DESIGN AND DEVELOPMENT OF PROCESS PLANNING SYSTEM AND CUTTER PATH SIMULATION FOR ROTATIONAL COMPONENTS

by

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CERTIFICATE

This is to certify that the present work on "Design and Development of Process Planning System and Cutter Path Simulation for Rotational Components" by M. Radhakrishnan has been carried out under our supervision and has not been submitted elsewhere for the award of a degree.

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ABSTRACT

In present work, a process planning system has been developed for rotational components with a turning centre in view. The system is capable of handling machining operations such as, facing, turning, taper turning, drilling, boring, shoulder boring, threading and grooving. Given the necessary geometrical and non-geometrical inputs, the system generates operation sequence, selection of cutting parameters, cutter path generation and performs simulation of cutter path.

The geometrical inputs are part geometry and raw stock geometry and the non-geometrical input is work material. The part geometry and raw stock geometry inputs are given with primitives of line and arc in a graphical environment.

The cutting parameters are retrieved on the basis of work material. The operation sequence is based on the features present in the component while sequencing is rule based. Finishing allowance is given in the raw stock for finish cutting. Based on the operation sequence, cutter path is generated with respect to a user defined datum point. The tool path is simulated by animation of the path using graphics utilities.

The process planning system is implemented on PC XT/AT and program is written in Turbo Pascal with Toolbox Graphics.

CHAPTER I

INTRODUCTION

Process planning is concerned with determining the sequence of individual operations needed to produce a given part or product [1]. The resulting operation sheet is documented on a form typically referred to as a route sheet. The route sheet is a listing of the production operations in sequence and associated machine tools for a work part. We will discuss the activities related to process planning, and the different approaches that are available, generation of cutter path to validate a process plan is also discussed.

1.1 FUNCTIONS OF A PROCESS PLANNING SYSTEM:

The following activities are carried out in a process planning system:

i) Selection of operations

ii) Selection of machine tools

iii) Selection of cutting tools

iv) Sequencing of operations

v) Grouping of operations

vi) Determination of cutting parameters

vii) Selection of work holding devices

viii)Selection of inspection instruments

ix) Selection of production tolerances

x) Generation of NC part programs

There are two approaches to process planning: manual process planning and computer-aided process planning. The details of the two approaches are briefly discussed in the following subsections.

1.1.1 Manual Process Planning:

Manual process planning procedure is very much dependent on the experience and judgement of the process planner. Each planner adopts his own options about what constitutes the best routing. Accordingly there are differences among the operation sequences developed by various planners. The significant portion of the total number of process plans used in manufacturing are not optimal. The generation of manual part program for numerical controlled machine tool needs skill and experience.

1.1.2 Automated Process Planning:

It makes use of the given part to automatically generate the manufacturing operation sequence. Computer-aided process planning system offers potentials for reducing the routine clerical work of manufacturing engineers. At the same time, it provides the opportunity to generate the routing which are rational, consistent and perhaps even optimal.

It is a link between computer-aided design (CAD) and computer-aided manufacturing (CAM). The work part data from the CAD can be used for a computer-aided process planning (CAPP) and

from this the raw stock requirement,cutting time and other related informations can be transferred to other functions of CAM. There are two approaches available for computer-aided process planning: variant and generative process planning.

Variant process planning uses library retrieval procedure to find standard plans for the parts for which plans already exist in the library. The standard plans are created manually by process planners. In generative process planning system (GPP) process plans are generated automatically for new components without referring to the existing plans. Upon receiving the geometric model the GPP can generate the required operations and operation sequence for the component and other process planning functions such as cutting tool selection, machine tool selection, process optimization.

In the following paragraphs, we will discuss the approaches to describe component through geometric modelling, and ways to produce process plan using GPP.

1.1.3 Geometric Modelling:

The geometric model necessary to generate the GPP can be of two ways.

a) Non-graphical approach

b) Graphical approach

In non-graphical approach the component is described as cylindrical elements and non-cylindrical elements. The cylindrical elements can be further described using cylinder,

taper, convex, and concave elements, and non-cylindrical elements can be described using planar, oblique and curved elements. The secondary features such as threading, chamfering, grooving, keyways etc. can be added on them.

In graphical approach, geometric modelling is used to describe the object. The geometric modelling is concerned with the computer compatible mathematical description of the geometry of the object. The mathematical description allows the image of the object to be displayed and manipulated on a graphics terminal. To use geometric modelling, the designer constructs the graphical image of the object through three types of commands as input to the computer. The first type of command generates basic geometry elements such as point, line and circle. The second command type is used to accomplish scaling, rotation or other transformation of these elements. The third type of command causes the various elements to be joined into the desired shape of the objects. During geometric modelling computer converts the commands into mathematical model, stores it in the computer data file and displays the image. The basic form used is wire frame to represent an object. In this form, the object is displayed by inter connecting lines.

The wire frame geometric modelling is classified in three types:

1. 2D - two dimensional representation is used for a flat object.

2. $2\frac{1}{2}$ D - goes beyond the 2D capability by permitting a three dimensional object to be represented as long as it has no side wall details.

3. 3D - this allows for the three dimensional modelling of a more complex geometry.

The most advanced method of geometric modelling is solid modelling in three dimensions. This method typically uses solid geometry shapes called primitives to construct an object.

The advantage with graphical method is, it is easy for the user to visualize and manipulate the component.

Based on the geometric model of the component and data stored for machine tool, cutting tool and auxillary conditions such as coolants, clamping devices, a detailed plan for manufacturing of the component is generated. The selection of operation and operation sequencing is based on geometrical and economical constraints. The selection of machine tool is done on the basis of horse power required, machine constraints to hold the component and efficient utilization of the machine tool. Cutting tool selection is done with due consideration to the interference of the work piece during machining.

The process plan can be generated for conventional machining operations (turning, milling, drilling, grinding etc.) and unconventional machining (ECM, EDM, etc.). Turning is the fundamental operation of metal cutting and it accounts for high percentage of machined parts. This process is different from other machining processes in the sense that the components

machined are symmetrical in nature and primary and secondary motions required to machine the component are also different.

1.2 GENERATION OF TOOL PATH:

Given the geometric model of the part, and the tools needed to machine the part, and the operation sequence, the tool path is generated. The method of accomplishing this using interactive graphics depends on the type of operation (e.g. profile milling, turning, sheet metal working) and the complexity of the part. The cutter path can be generated by automatic routine or by user interactive inputs. The automatic routines include turning, profile milling, point to point hole piercing because there involve 2-D or $2\frac{1}{2}$D operations and such operations are available for the use of automatic routines. However, if a geometric representation has been made using 3-D for which solid modeller is amenable then automatic routines can also be used. The user interactive inputs are ofcourse, possible for any representtion.

The procedure begins with defining a starting position of the cutter. As the tool moves along the path, corresponding APT motion commands can be automatically generated. The graphical mode helps the user with the opportunity to insert post processor statements at appropriate points during program creation. These post processors would consists of machine tools instructions such as feed rates, speed and control of the cutting field.

The generated tool path can be used to simulate the cutting action by animation for tool interference and real time

simulation. The simulated motions can be displayed on the screen in any one of modes. (1) High speed motion which reduces the time to verify the tool path, (2) Actual speed which shows the tool feed at the command rate, (3) freeze mode which stops the tool motion for close inspection and (4) Stepping mode which displays the tool path in discrete steps.

1.3 LITERATURE SURVEY ON PROCESS PLANNING:

As discussed earlier in Sections 1.1 and 1.2 lot of computation and data handling are required to evolve the process plan. It calls for engineering database consisting of data concerning work material, manufacturing operations and cutting tools. Various people have developed process planning system based on variant approach and generative approach of this we will discuss some of them in the subsequent paragraphs.

The most complete and integrated system for process planning and NC part programming is developed by Evershim et.al [2]. This system caters to rotational and sheert metal components. AUTAP and AUTAP-NC system developed by them require the part description which is dissected into geometrical and technological data. The position of the geometrical elements for rotional components is described by describing the outer contour from left to right and inner contour from right to left. For sheet metal components the position of each geometrical element is required to be described. The part description is stored in a centralised database. The system can select work material, operation sequence from network

of operations depending upon the shape and dimensions of part and order data. Also there are databases for chucks, cutting data etc. The machine tool is selected by economical and technological range of operation.

The logical generation of part program and macros depends upon the description of finished stock and raw stock. The AUTAP-NC system is capable of functioning as a stand alone system or as an integrated system. The system functions in a dialogue or batch mode. There is also facility for the graphical generation of the tool path which can be used for checking the sequence of operations.

Though it is the most complete system but it does not provide interactive way of describing the object. The object has to be described as a series of cylindrical, concave, convex and taper surfaces to generate the part geometry.

The process planning module developed by Ming Shyu et al. [3] interactively gets the input of finished component, raw geometry and operation sequence. Based on this it selects optimum cutting parameters and cutting tools and generates NC part programme, simulation of cutting tools along the cutter path for interference of cutting tool with work piece. The above system does not generate the operation sequence based on the user input, but it generates part programme for the given operations. So the operation sequences are not optimized.

Ravichandran et al [4] developed a software package for process planning of rotational components. This system is a stand

alone system and does not cover the NC part program and cutter path simulation. The package has the provision to be integrated with a CAM system. Also it is able to generate machining parameters and if the user wants it can optimize the parameters.

A code system for rotational parts was developed by Hann R.A. [5]. The system stores the part programs and process plan for various part families. The process plan and part program canbe retrieved by using a code. Coding is done based on the component shape, manufacturing process used. If a particular part does not have part program and process plan, it modifies interactively one of the similar object program to suit the need. It is completely non graphical approach and user has to do more work to generate the process plan and part program.

A decision support system for process planning was developed by Chitta [6]. The system generate coding for each part geometry based on group technology. It suggests the operations required bhased on the part family and its optimize cutting parameters for each operations. Here operation sequencing is not carried out for each part. The process planning system developed by Vittal [7] generates operation sequence, selection of machine tools, and selection of cutting tools for rotational components. Takkar [8] has designed a process planning system in a database environment. For a specified operation it selects cutting tools interactively with the user and optimize the cutting parameters based on machine tool selection. It generates part program for the specified operations.

1.4 SCOPE AND ORGANIZATION OF THE THESIS:

From the Sec. 1.3, it can be seen that the concept of complete interactive graphical approach for process plan and cutter path simulation by animation has not been adequately attended for. Hence the present attempt has been made to generate the process plan for rotational components which includes operation sequence, cutting parameters, cutter path simulation by animation, and cutting time. For this part geometry description through geometric modelling, retrieval of cutting parameters, operation sequencing through specified rules, generation of cutter path, and simulation of the cutter path through animation are done.

The organisation of the thesis is as follows:

The Chapter II discusses the system analysis and design of a process planning system and Chapter III discusses about implementation aspects. Chapter IV gives tested examples in the program and Chapter V discusses about user manual. Chapter VI discusses about conclusion and suggestion for future work.

CHAPTER II

SYSTEM ANALYSIS AND DESIGN

This chapter presents the analysis and design of process planning for rotational components. In rotational parts the surfaces of revolutions are getting machined. The parts are formed by rotating a generatrix (a line) with respect to the directrix (a circle). The typical operations for such components are facing, turning, taper turning, drilling, axial boring, shoulder boring, external grooving, internal grooving, external threading, internal threading.

The system considered consists of a turning centre. Following are some salient capabilities of a turning centre.

i) Simultaneous movement in two axes helps the operations to be carried out without any change in settings. Linear and circular interpolation are used for inclined and circular cutting respectively. Thus wide range of operations are possible.

ii) Wide range of spindle speeds are available which helps to select optimum cutting parametrs for each operation.

iii) The tool turret which holds different type of tools is automatically indexed in between different opertions.

iv) The accuracy and repeatability of dimensions are very high.

v) The setup time is very low. Thus machine can switch over to different jobs in less time.

vi) System related to part geometry, machining instructions are stored in the form of tape.

It differs from conventional lathe in the sense that it is a programmable automatic machine in which the process is controlled by letters, numbers and symbols. This characters form a program of instructions commonly known as part programming designed for a particular work part or job. The implementation is with respect to HITECH-20 [9] of Fanuc Japan. The turning centre has the capability of adjusting the distance between centres and several automatic and advanced features.

Process planning functions eventually deals with the following information or data which are generated using part geometry, raw stock geometry, material characteristics and the characteristics of turning centre.

1. Operation sequence
2. Cutting Tool(s) for each operation including
   (a) Tool geometry
   (b) Tool life
3. Cutting parametes for each operation including
   (a) Cutting speed
   (b) Feed
   (c) Depth of cut
   (d) Number of cuts
4. Opeation (machining) time.

5. Auxillary devices of each part geometry

Using this, the system further generates following information for part geometry for part programming and for cutter path simulation.

(i) Numerical control part programming

(ii) Cutter location file

(iii) Tool nose compensation for finish cutting

2.1 SYSTEM DESCRIPTION:

The following modules are necessary to generate the above mentioned information:

i) Part geometry description

ii) Raw stock geometry description

iii) Cutting parameters selection

iv) Determination of finish cut geometry

v) Determination of opertion sequencing

vi) Determination of cutter path

vii) Determination of finished cutter path with tool nose radius compensation.

The inter-relationship between different modules are as shown in Fig. 2.1. Each description is discussed in detailed as below.

2.1.1 Part Geometry Description:

In part geometry description the rotational part is described using with primitives (or elements) of point, line, circular arc, curve. In our discussion we will confine ourselves with point,

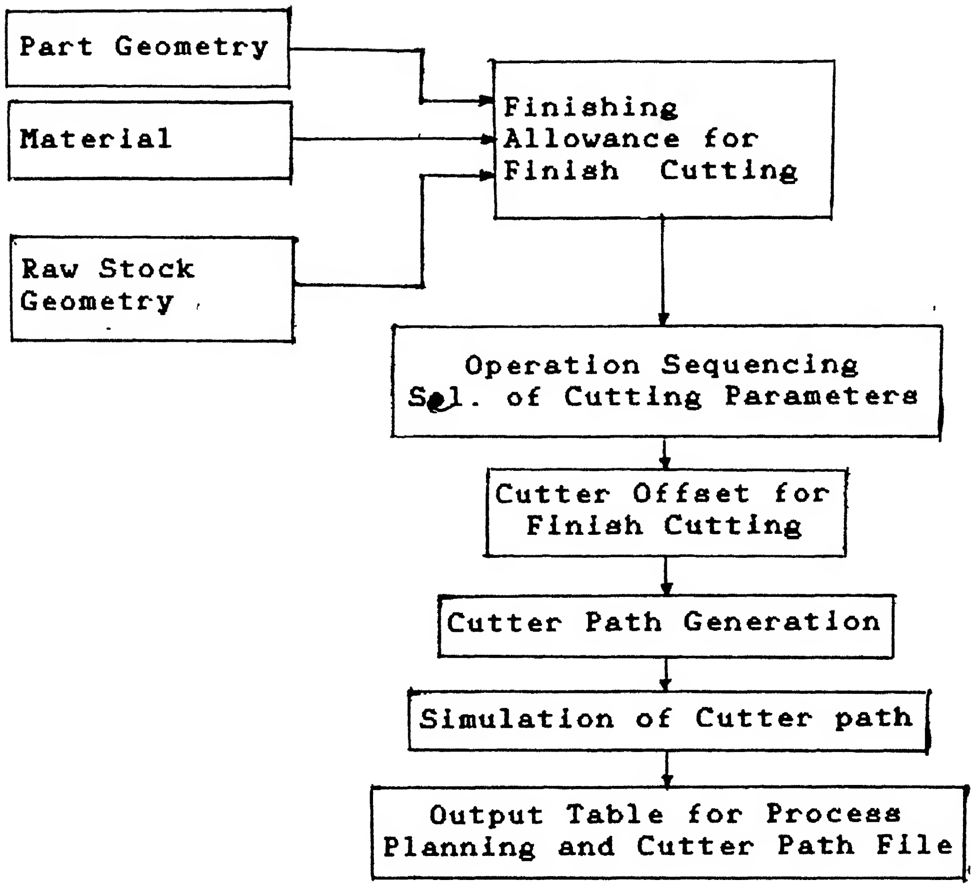


Figure 2.1: Master Flow Chart for Process Planning System.

line and circular arc. In general there are several combintions possible to describe and specify the elements. Table 2.1 lists some of the possible combinations to describe line and an arc. This combination determine position and characteristic size of an element. The straight line has four degrees of freedom and needs four input conditions to determine it. The circular arc has five degrees of freedom and needs five input conditions to determine it. The point has two degrees of freedom and needs two input conditions for its determination.

The tangential relationship between two elements can also be used to describe an element with less number of known input conditions. For example to describe an arc and a line, it is sufficient to have 8 input conditions with tangential relationship.

The arc which has combination of case 2 in table 2.1 has two possible arcs. The arc may be either clockwise (CLW) or counter clockwise (CCLW). In order to reduce the multiple solution, one more input condition is required (CLW or CCLW). However, it does not reduce the number of input condilons.

Hinduja [10] has derived the following empirical formula for the number of known input conditions necessary to determine a group of elements.

$$N_R = 4I + 5J - 2K$$

where

N_R = The number of conditions required to describe a group of elements

Table 2.1: Various Line and Arc Options.

Line

1. a) Starting point (X and Y coordinates)

   b) Ending point (X and Y coordinates)

2. a) Starting point (X and Y coordinates)

   b) Any one of the End point (X or Y coordinates)

   c) Slope of the line

Arc

1. a) Starting point (X and Y coordinates)

   b) Ending point (X and Y coordinates)

   c) Centre point (X and Y coordinates)

2. a) Starting point (X and Y coordinates0

   b) Ending point (X and Y coordinates)

   c) Radius

3. a) Starting point (X and Y coordinates)

   b) Centre point (X and Y coordinates)

   c) Included angle (between start point and end point)

4. a) Starting point (X and Y coordinates)

   b) Centre point (X and Y coordinates)

   c) Ending angle

I = The number of line elements in a group

J = The number of arc elements in a group

K = The number of change points (a change point is the number of two consecutive elements).

If the total number of input conditions (N_I) are equal to N_R then it is sufficient to describe a group of elements. Only independent conditions are considered and redundant conditions are eliminated for consideration. If a circular arc has input conditions of starting point (X and Y coordinates) centre points (X and Y coordinates) and radius (r) then one condition becomes redundant.

A part geometry description as shown in Fig. 2.2 is used to illustrate the group of elements. The number of input condition N_I is less than N_R till element no. 3. So the conditions are insufficient to describe. But with input conditions of 4th element,l it becomes equal to N_R and hence the group elements can be described.

Irrespective of input conditions are converted into following data and used for further analysis:

i) X_S : starting point (x coordinate)

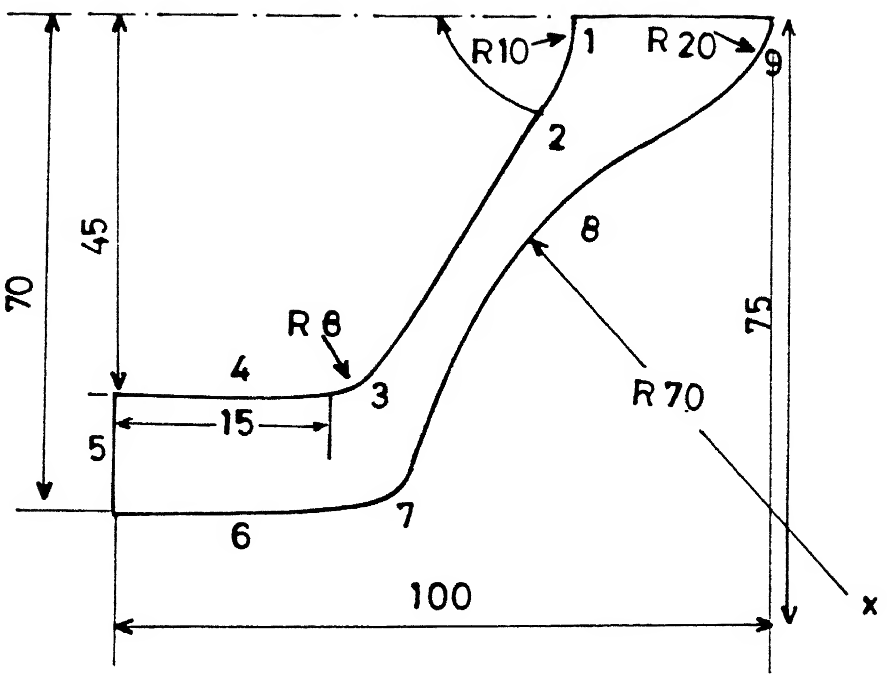
ii) Y_S : starting point (y coordinate)

iii) X_F : ending point (x coordinate)

iv) Y_F : ending point (y coordinate)

v) X_C : Centre point (x coordinate)

vi) Y_C : centre point (y coordinate)



X_c, Y_c – Centre point

X_s, X_s – Starting point

Y_f, Y_f – Ending point

A – Angle

T – Tangential

R – Radius

Element ϕ	Input Conditions	N_I	N_R
1	Y_c, Y_s, R	3	5
2	A, T	5	7
3	R, Y_f, X_f, T	9	10
4	Y_f, X_f, T	12	12
5	A, Y_f	14	14
6	A	15	16
7	R, T	17	19
8	X_c, X_c, R, T	21	22
9	Y_c, Y_f, R, T	25	25

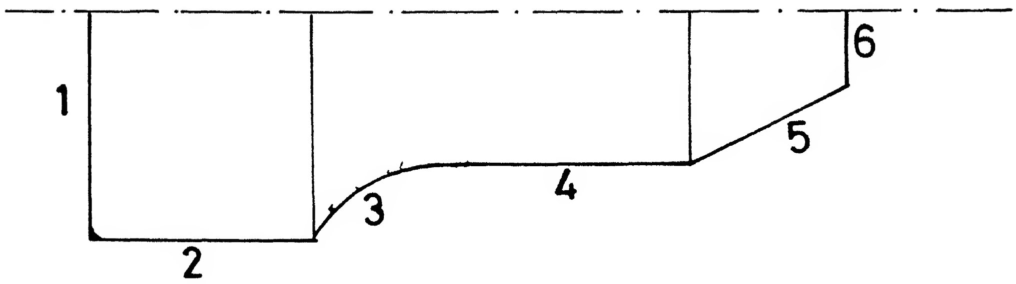
Figure 2.2

Since the part being considered is rotational it is sufficient to have half side elements from the axis. Each elements is analysed and segregated as diameteral and face elements. The line elements parallel or inclined to the axis and circular arc elements are considered as diameteral elements while the elements perpendicular to the axis are termed as face elements as shown in Fig. 2.3. Based on the diameteral elements, the maximum, minimum diameters are found out and using the face elements the starting point, ending point of external/internal contours are established. The two extreme face elements are used to segregte the external and internal contours based on the direction change in X axis. The codification of whether an element is external/internal added to each element for further analysis.

After the part geometry discription the surface finish, surface finish tolerances to be achieved after machining for each element has to be given.

2.1.2 Raw Stock Geometry:

The raw stock geometry has to be described in the same way for finish geometry of the component as described in Section 2.1.1. The cutting boundary (the material to be removed from raw stock geometry) is determined by extracting the contour from raw stock geometry and finished geometry. Usual offset is given from the part geometry in the cutting boundary for finish cutting operations.



1, 6 - Face Elements
2, 3, 4, 5 - Diameteral Elements

Figure 2.3

2.1.3 Cutting Parameters Selection:

The cutting parameters are stored for HITECH-20 turning centre for different materials. Based on the material, speed, feed, depth of cut, finished depth of cut, feed for finishing and roughing operations are selected. For finishing operation, the feed value for each element depends upon the surface finish of the each element.

2.1.4 Sequencing of Operations:

The part geometry and cutting boundary is used to generate the operation sequence. Using the diameteral elements of the part geometry it is determined whether part geometry needs double setup or single setup to carryout the operations. If the larger diameter is not present at any one of the ends the operations are carried out in double setup otherwise single setup is sufficient. In case of internal operations if the smaller diameter is not present at any one of the ends, the same rule will apply. In case of double setup the part geometry is divided into two segments and operation sequence is carried out.

The selection of operations are based on form features such as face turning, profile roughing, finish turning, boring etc. Ming Shu [3] has suggested a rule for sequencing the operations as shown in Table 2.2.

The same rule is also used here to sequencing the operations. Firstly the opertions are carried out according to sequences given in the Table 2.2. Then within the operation the sequence is

Table 2.2: Operations Sequence.

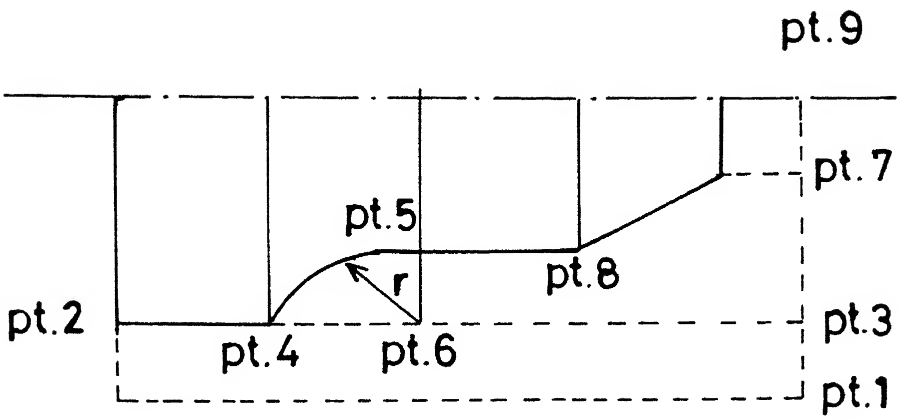
Sequence	Operation Type
a	Face roughing
b	Outside roughing
c	Drilling
d	Inside roughing
e	Inside finishing
f	Outside grooving
g	Inside grooving
h	Inside threading
i	Outside threading

carried out based on the part geometry. For example in turning the raw stock is turned till the largest diameter as shown in Fig. 2.4. This forms the first sequence in this operation. And the turning is continued till next largest diameter and so on.

In case of straight turning two points are identified and for taper turning three points are identified and for circular arc cutting four points are identified. For further analysis and for displaying the operation for both external as well as internal. They are called as operation points. For drilling the data is identified same way as turning. Each operation is stored with operation name, sequence number, and the operation points as data.

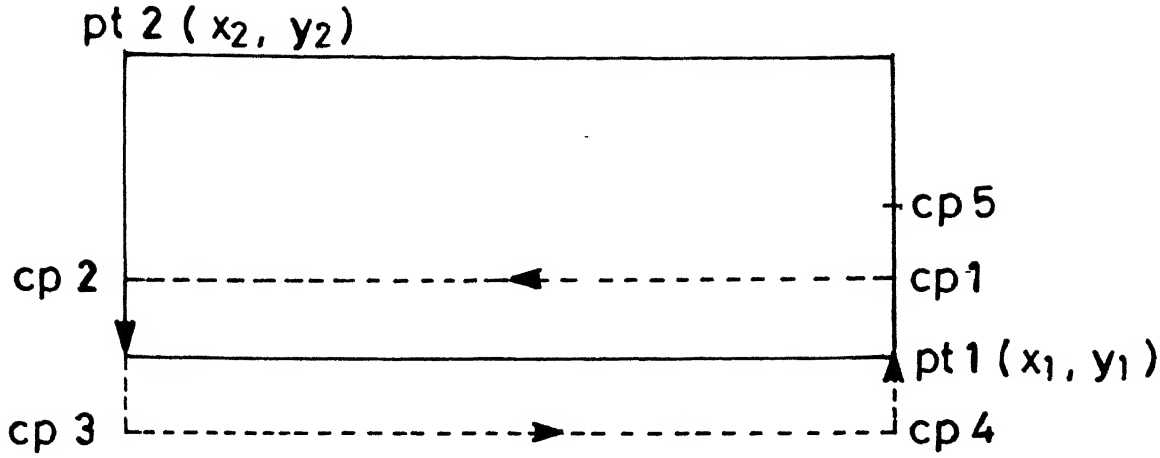
Generation of Cutter Path:

Using the operation sequence generated the tool path and number of cuts are determined. Each tool path will have the starting point ending point and time required to tavel. For example in case of turning the operation start point will be CP1 as shown in Fig. 2.5 and end point is CP2 then tool relieves by an relief input (path CP2, CP3) and trvel to CP4. The next cutter path is CP5 and it continues till operation pt1. In case of inclined cutting. The line eleement intersecting point is found out with a straight line drawn from CP1 and CP2 is calculated. In case of circular cutting intersection is found with the circular arc. Every cutting path will have 4pts (CP1, CP2, CP3, CP4) for its description. The finished cutter path will have the same path of contour desribed. For finished cutter path the tool path is given off set based on the element, drive path, and tool nose radius for tool nose radius compensation.



pt.1 , pt.2 - Straight Turning
pt.3, pt.4, pt.5 & pt. 6 Circular Arc Turning
pt 7, pt 8, pt 9 Taper Turning

Figure 2.4



CP1 (x coordinate) = x1

CP1 (y coordinate) = y1-del

CP2 (x coordinate) = x2

CP2 (y coordinate) = y1-del

CP3 (x coordinate) = x2

CP3 (y coordinate) = CP2 (y coordinate) + rel

CP4 (x coordinate) = x1

CP4 (y coordinate) = CP3 (y coordinate)

CP5 (x coordinate) = x1

CP5 (y coordinate) = CP1 (y coordinate) + del

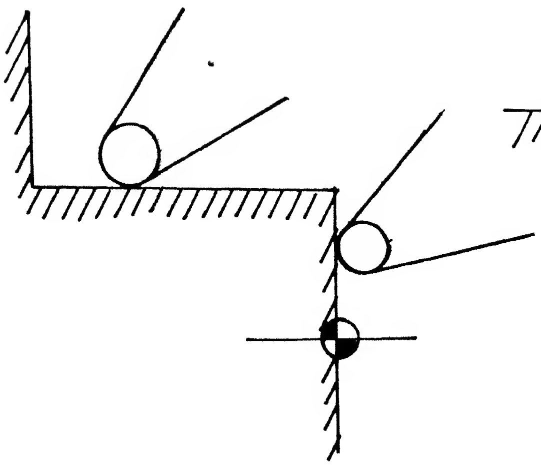
del = depth of cut

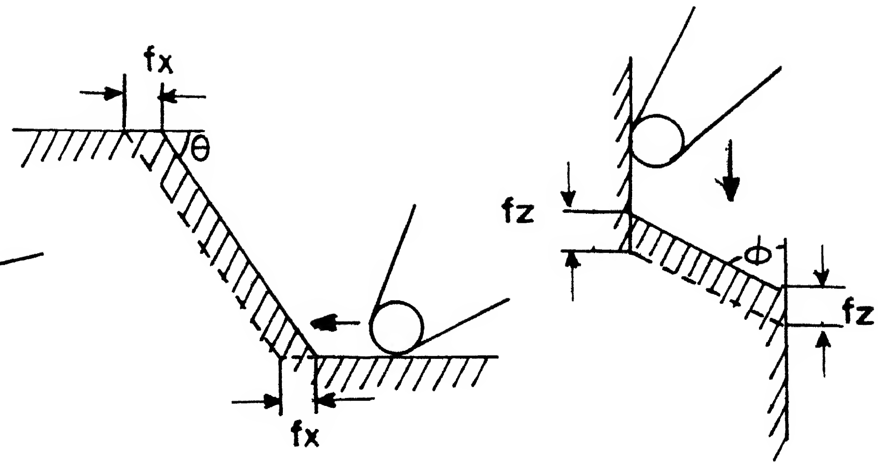
rel = tool relief amount

Figure 2.5:

In part programming the tool nose is considered as a point. However, the actual tool have a roundness of radius r. While chamfering, taper turning or circular arc cutting the workpiece is cut too short or too much due to tool nose radius r. Tool nose compensation functions are available for excessive or insufficient cutting in part programming. Similarly for the cutter path generation the exact offset should be given for proper cutting.

When cutting extenal or internal or end face it can be cut as per drawing even if the tool nose is considered as one point (Virtual tool nose point) as shown in Fig. 2.6. In case of straight cutting virtual tool nose point will coincide with the element start point and end point. However, in the case of taper turning if the element start point and end point coincide with the virtual tool nose point excessive or insufficient cutting takes place as shown in Fig. 2.7 because of tool nose position in cutting is different. To prevent this improper cutting tool nose compensation is calculated using taper angle, tool nose radius r and drive path. The tool path is shown as broken line in for each machined profile. In circular cutting ~~to~~ the tool cuts the work piece along the arc with tool nose radius r. Due to this insufficiency will be caused as shown in Figs. 2.8 & 2.9. For this the system calculates tool path for convex circular arc r larger by tool nose radius along the arc direction and in case of convex are r smaller by tool nose radius. This applicable for both external as well as internal.





$\phi = 90 - \theta$

$fx = 2r(1 - \tan\phi/2)$ 2.1

$fz = r(1 - \tan\theta/2)$ ... 2.2

r = Tool Nose Radius

fx, fz = Compensation in x and y Direction .

Figure 2.6

Figure 2.7

Point 1, 2, 3 & 4 - Virtual tool nose points.

1- Actual Profile, 2-Tool Travel Path

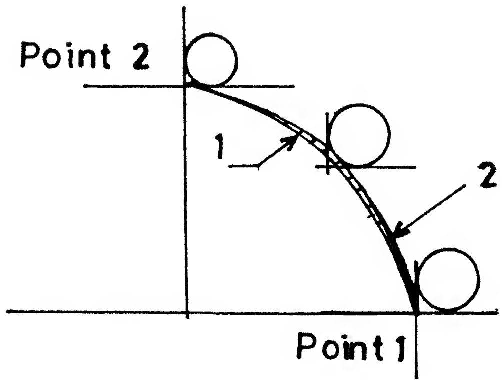


Figure 2.8

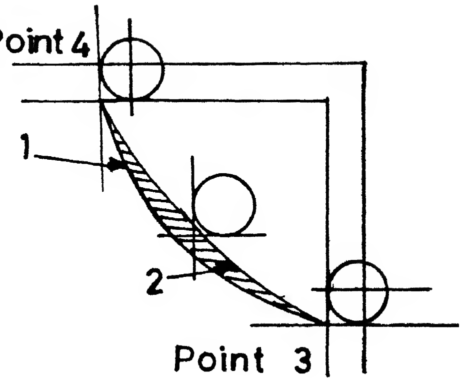


Figure 2.9

Simulation:

Based on the cutter path generated above is used to animate the every cutter pth. Given the datum point of the tool and relieving necessary for each path the tool path is simulated on the screen. From this itself the cutting time is foundout for each cutting motion.

CHAPTER III

IMPLEMENTAION OF PROCESS PLANNING SYSTEM

With the system analysis presented in view in Chapter II, a software package has been developed on PC-XT/AT. This chapter presents the details of implementation: system splecifications, menu structure, environment for operating the system and implementation of different modules. Section 3.1 discuss about system specifications, in section 3.2 about the environment, in section 3.3 about menu structure, in section 3.4 about the necessary inputs to run the program and in section 3.5 about sequencing of operation and cutter path generation. Section 3.6 discuss about the simulation by animation of each operation, output of the operation sequence, and cutter location file.

3.1 SYSTEM SPECIFICATIONS:

The program has been written using Turbopascal with toolbox graphics. Some of the basic requirement to run this program are:

1. MS-DOS environment
2. AO graphics adapter (HGC, CGA, EGA)

The graphical environment is setup in the MS DOS environment using the following procedure libraries of tool box.

i) Typedef.sys

ii) Graphics.sys

iii) Kernel.sys

iv) Windows.sys

The following procedure libraries which are created in the program with specific requirements:

a) Strin.pas (to check for the input data and validity of the data)

b) incom.pas (for display of command for every menu option)

c) arfile.pas (for changing the input data for different draw options into standard data

d) Newmenu.pas for loading different windows for menu options Overlay procedures have been used for memory management. It is completely menu driven and offers adequate ease of operation.

e) Sec. pas (for describing secondary elements, threading and grooving).

f) Drt4.pas (for sequencing the operation and cutter path simulation).

g) Incom.pas (display of messages for input).

3.2 ENVIRONMENT:

The screen is divided into four parts as shown in Fig. 3.1. The top left part of the screen is the drawing area. On this part the visual area of the drawing is displayed. Visual area is the portion of the drawing displayed in the screen. On this part the geometric inputs are described. The right top displays menu and left bottom displayes previous input entry. The bottom left is

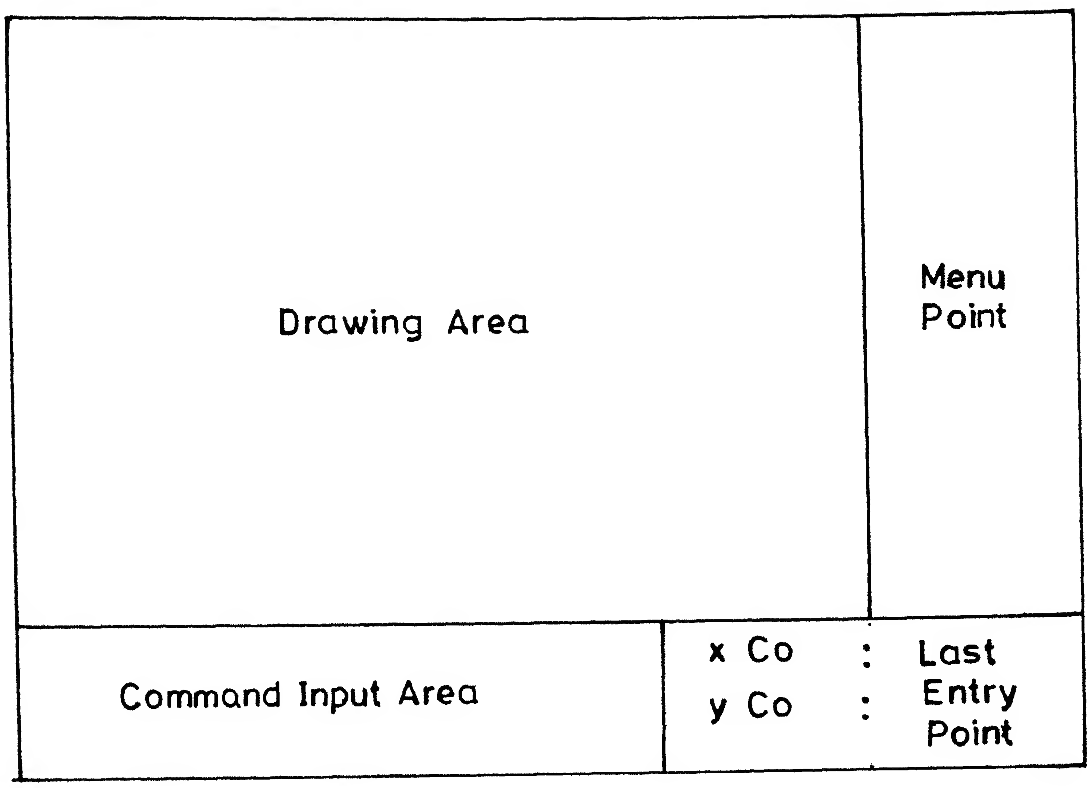

Drawing Area
Menu
Point
Command Input Area
x Co :
y Co :
Last
Entry
Point

Figure 3.1

used for getting the geometric and non-geometric inputs. For every menu option commands are displayed here. Care has been taken for the validity of the input for each command.

3.3 MENU STRUCTURE:

The complete menu structure of the package is shown in Fig. 3.2. The geometric and non geometric inputs are given by invoking the relevant menu option. The PgDn key is used to invoke the curser and arrow keys (up and down) of the numeric keypad is to move the curser. By keeping the curser in the command by pressing 'Return' key the command will be executed. There is a provision for going to the submenu or to the main menu from every menu. When the visual screen is activated through a menu option the menu window from which the action is invoked remains intact while working in the drawing area and activity in the drawing area gets completed for the previous menu option. The next menu can be activated by pressing 'PgDn' key. All the menu slides are stored with .WIN extension and loaded when the menu option is invoked.

3.4 GEOMETRIC AND NON-GEOMETRIC INPUTS:

The following are the necessary geometric and non-geometric inputs to run the program.

i) Settings

ii) Part geometry input

iii) Raw stock input

iv) Selection of cutting parameters

They are discussed in detail in the following sections.

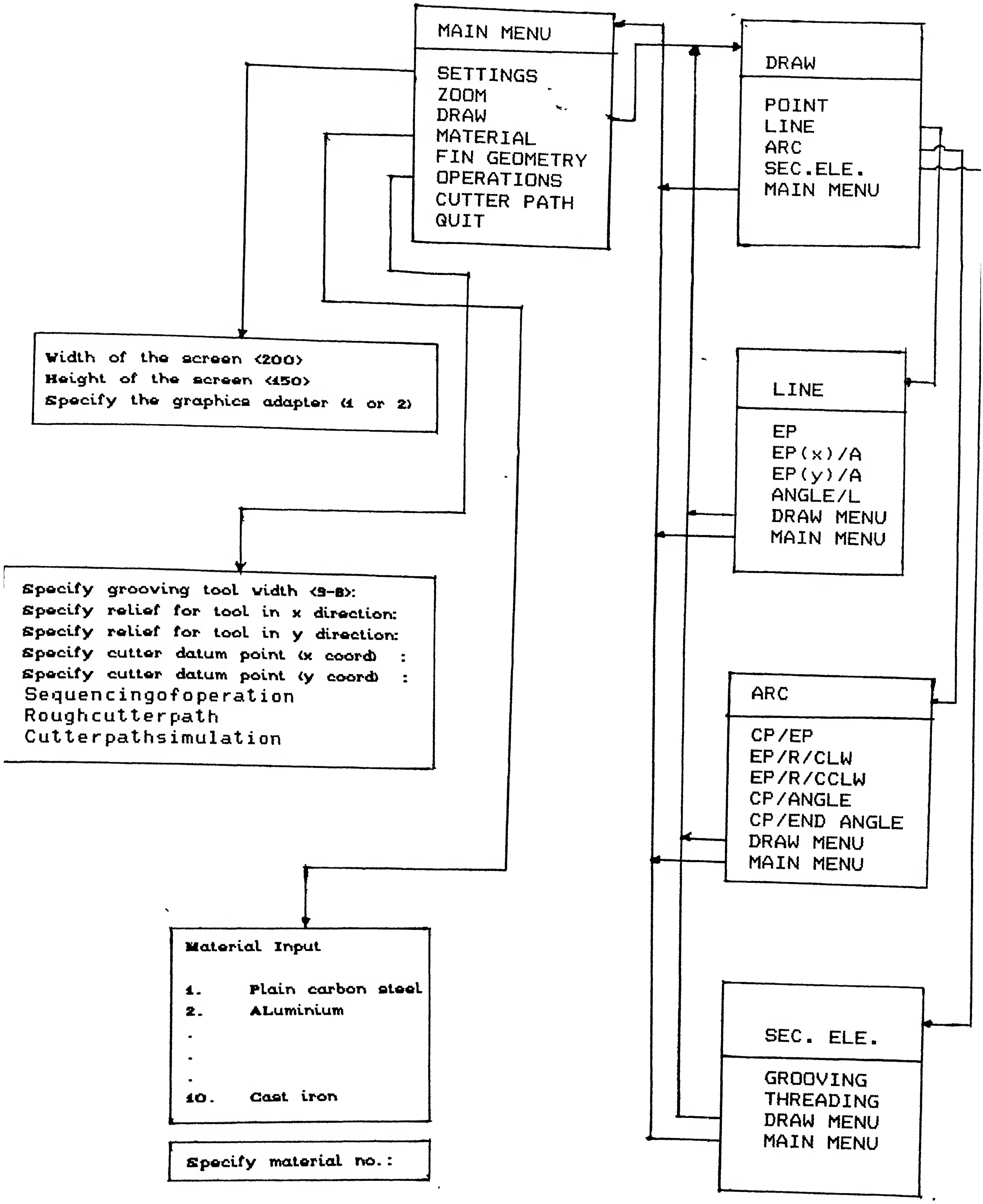

MAIN MENU
SETTINGS
ZOOM
DRAW
MATERIAL
FIN GEOMETRY
OPERATIONS
CUTTER PATH
QUIT
DRAW
POINT
LINE
ARC
SEC.ELE.
MAIN MENU
Width of the screen <200>
Height of the screen <150>
Specify the graphics adapter (1 or 2)
LINE
EP
EP(x)/A
EP(y)/A
ANGLE/L
DRAW MENU
MAIN MENU
Specify grooving tool width <3-8>:
Specify relief for tool in x direction:
Specify relief for tool in y direction:
Specify cutter datum point (x coord) :
Specify cutter datum point (y coord) :
Sequencingofoperation
Roughcutterpath
Cutterpathsimulation
ARC
CP/EP
EP/R/CLW
EP/R/CCLW
CP/ANGLE
CP/END ANGLE
DRAW MENU
MAIN MENU
Material Input
1. Plain carbon steel
2. ALuminium
.
.
.
10. Cast iron
Specify material no.:
SEC. ELE.
GROOVING
THREADING
DRAW MENU
MAIN MENU

Figure - 3.2

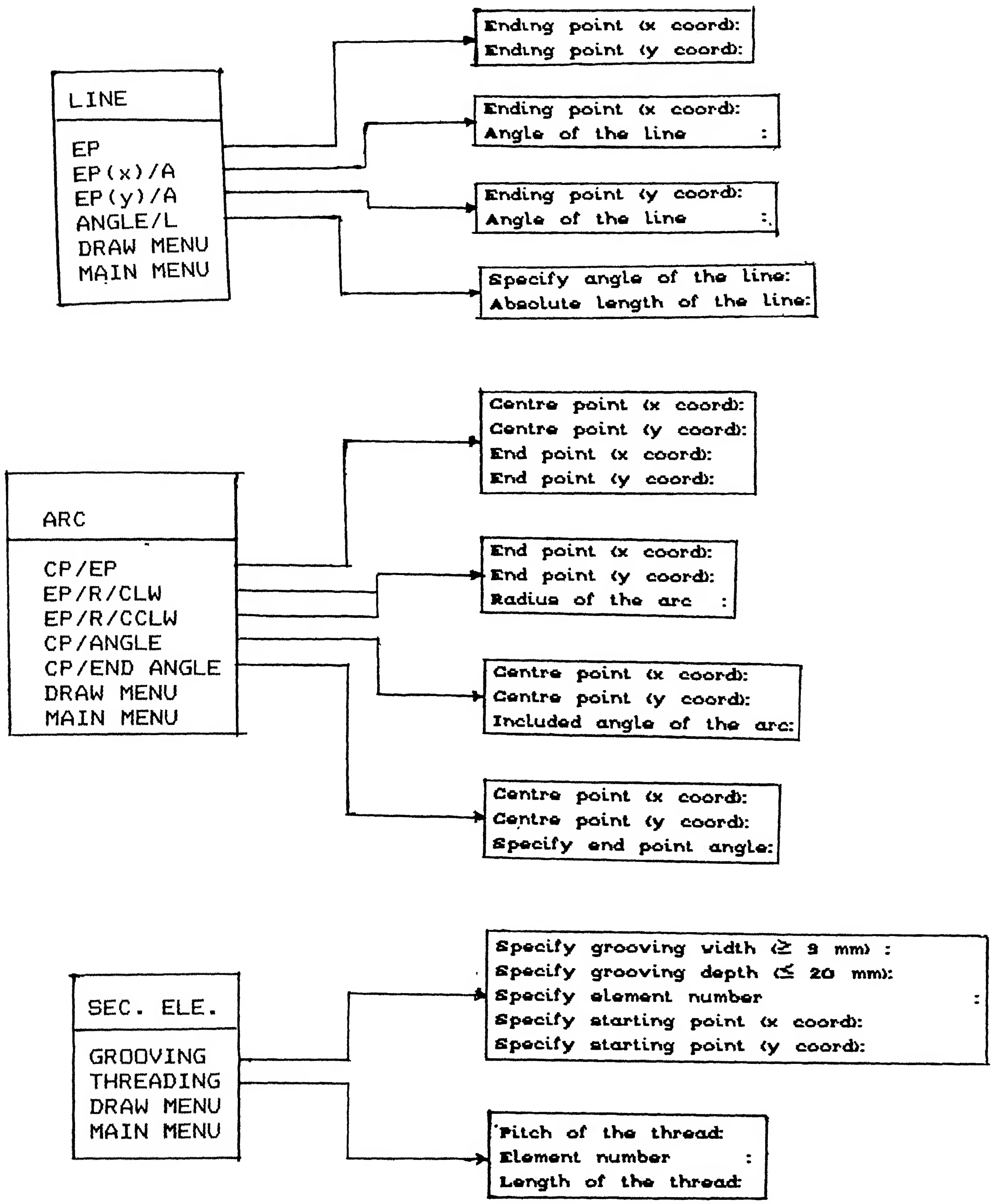

LINE
EP
EP(x)/A
EP(y)/A
ANGLE/L
DRAW MENU
MAIN MENU
Ending point (x coord):
Ending point (y coord):
Ending point (x coord):
Angle of the line :
Ending point (y coord):
Angle of the line :
Specify angle of the line:
Absolute length of the line:
ARC
CP/EP
EP/R/CLW
EP/R/CCLW
CP/ANGLE
CP/END ANGLE
DRAW MENU
MAIN MENU
Centre point (x coord):
Centre point (y coord):
End point (x coord):
End point (y coord):
End point (x coord):
End point (y coord):
Radius of the arc :
Centre point (x coord):
Centre point (y coord):
Included angle of the arc:
Centre point (x coord):
Centre point (y coord):
Specify end point angle:
SEC. ELE.
GROOVING
THREADING
DRAW MENU
MAIN MENU
Specify grooving width (≥ 3 mm) :
Specify grooving depth (≤ 20 mm):
Specify element number :
Specify starting point (x coord):
Specify starting point (y coord):
Pitch of the thread:
Element number :
Length of the thread:

Figure 3.2

3.4.1 Settings:

This helps the user to define the visual area of the drawing limits. To fix the visual area the user has to specify either width or height of the screen. The screen coordinates are normalised based on the width (height) to have equal scale.

Height (given width) = Width x Aspect ratio

Width (given height) = Height x (1/Aspect ratio)

Aspect ratio = 1.33 for HGC

= 5/4 for EGA

3.4.2 Part Geometry Input:

As described in Section 2.1.1,using the primitives of points, line, and arc, the part geometry is described. The following convention is followed to give the geometric input. The geometric description must have to start from left end of the geometry with a point option in the Draw menu. Then series of inputs are given with the options given in Table 2.1 in the Draw menu. As stated om Section 2.1.1, different line and arc options are implemented except group of elements. The end of the part geometry input is recognized, when the starting point of the part geometry and end point of the last element entry is same, or the last element y coordinates equal to zero. After the part input is given the system segregates diameteral and face elements and data are stored in standard format. Along with the above information, each element is analysed for external and internal contours. Part geometry is stored in a file (GEOM.DTA). All records of the files corresponds to the each element. The fields in the record are:

XS : Starting point (X coordinate)

YS : Starting point (Y coordinate)

XF : Ending point (X coordinate)

YF : Ending point (Y coordinate)

XC : Centre point (X coordinate)

YC : Centre point (Y coordinate)

ELNUMBER : Element Number

CLASS : Diameteral or face

TYPE : External or internal

The secondary elements of grooving and threading are given after the part geometry input is completed. Given the necessary inputs for the grooving as listed in the menu structure (grooving width, grooving depth, element number) and for threading (pitch, element number, length of the thread), this secondary element gets added to the corresponding elements.

3.4.3 Raw Geometry Input:

The input for the raw stock geometry has been given in the same way as the part geometry input as described earlier. Only straight line elements are used to describe the raw stock geometry. After the raw stock inputs are given the system checks whether sufficient material is available for machining. If not, the system asks for the reinputting, for the raw stock and part geometry. Here the file is stored in a file (RAWGEOM.DTA) with the standard format. The file has the same structure as (GEOM.DTA).

3.4.4 Selection of Cutting Parameters:

As stated earlier in Section 2.1.3 for HITECH-20, the cutting parameters are stored in the file (MATER.DTA). By invoking the material in the menu option giving the material number. The numbering scheme is presented in the following table.

1. Plain carbon steel (1045)
2. Medium carbon steel (4140)
3. Alloy steel (8620)
4. Tool steel (M-10 TLSL)
5. Stainless steel (303-SST)
6. Stainless steel (316-SST)
7. Aluminium (6061-ALUM)
8. Inconel
9. Copper
10. Cast iron

The cutting parameters namely cutting speed, feed, depth of cut, finish depth of cut for turning, drilling, boring, grooving are retrieved except threading. In case of threading the first depth of cut is retrieved from the file and subsequent depth of cuts are calculated using the folowing expressions.

Depth of thread cutting t = 0.6495*p*2

Di+1 = Di*√i

Di = First thread cutting depth (retrieve from material file.

Di+1 = (i+1)th thread cutting depth.

The cutting operation continues until 'Di+1' becomes equal to 't'.

For grooving the user is asked to provide width of the cutter for every grooving from a set of stndard widths (3,5 and 8). The cutter width must have to be less than width of the groove to be machined. The material file will have the records correspondsto the material number. The fields in the records are (finspeed : finish cutting speed, findepth : finish depth of cut, roudepth : rough depth of cut, rouspeed : roughing cutting speed. grspeed : grooving cutting speed, thspeed : thread cutting speed.

3.5 SYSTEMS OUTPUT:

Based on the inputs given by the user operation sequencing, cutter path generation and simulation of cutting tool by animation are carried out. They are discussed in detail as below:

3.5.1 Operation Sequencing:

The system analysis whether part geometry requires double set up or single set up to carry out the operations as described in Section 2.1.4. After the number of set up have been decided the part geometry analysis for form features. The operation sequence will follow the rule specified in Table 2.2. In case part geometry needs two set ups to carry out the operations, transformation is carried out with respect to the start face of the largest diameter and operation sequencing is done. We will discuss below the details of operation sequence.

If the form feature is present in the part geometry the corresponding feature is extracted in the cutting boundary and

data for each feature is also found out. After the extraction the cutting boundary is updated and next rule is applied. For example, as shown in Fig. 3.3, the first operation is facing as per the rule. Then the turning operations (2,3 and 4) are carried out. Then finishing opertion is carried out along the contour which forms the fifth operation. The sixth and seventh operations are grooving and threading respectively. Since the largest diameter is not at the end, the transformation is carried out with respect to face A and turning opertion (8) and finishing operation (9) are carried out. All the operation points are stored in a file as a record along with tht following information.

i) Name of the opertion

ii) Operation number (according to the sequence)

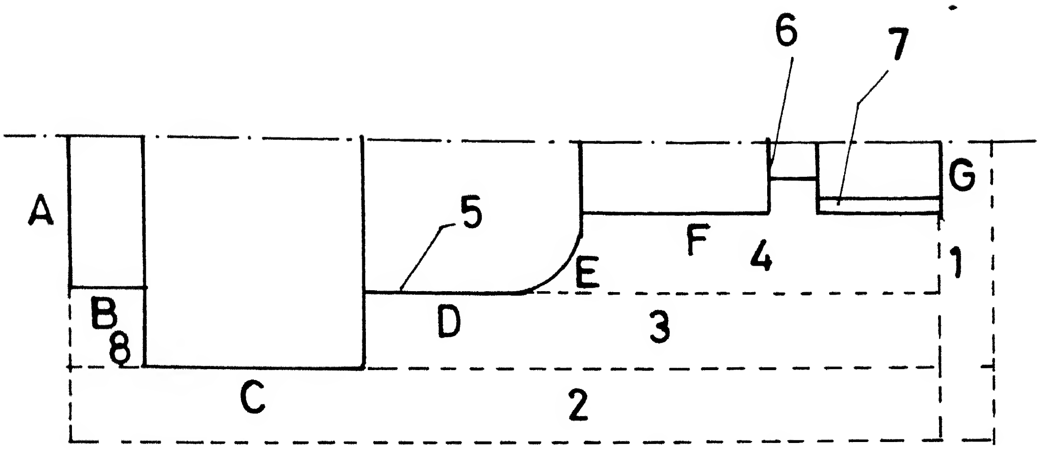
iii) Whether the operation is done in first set up or in second set up.

The file used here is "OPER.DTA". In the operation file, each operation is stored as a record with following data:

XOP1 - operation point (1) (X coordinate), YOP1 - operation point (1) (Y coordinate), XOP2 - operation point (2) (Y coordinate), XOP3 - operation point (3) (X coordinate), YOP3 - operation point (4) (Y coordinate), OPNUMBER - operation number, OPNAME - name of the operation, OPCODE - set up.

3.5.2 Cutter Path Generation:

Based on the information generated in operation sequence is used to generate the cutter location file (CL file). Every



No	Operation
1.	Facing
2.	Turning
3.	Turning
4.	Turning
5.	Finish Turning(Elements C, D, E, F, G)
6.	Grooving
7.	Threading
8.	Turning
9.	Finishı Turning (Elements A, B)

Figure 3.3

operation record is used and using rough depth of cut, finish depth of cut the operations are divided into number of cuts and for each cut the starting point, ending point are stored along with time required to travel unit length. In the cutter path file, following data are stored starting point, ending point, name of the operation, time/unit length as a sequential file. As stated earlier, every cutting motion will have four paths to describe it.

Based on the information geneated in cutter path file, the simulation by animation of roughing operations are carried out. Since some time limit is required to read the data for simulation, the time/unit length is converted into the length required to travel for every 10 fraction of seconds. The cutter path sequence allowances are given for tool relieving. Here the tool is considered as a point and animation is carried out.

3.5.3 Tool Nose Radius Compensation:

In driving the tool path for finish cutting tool nose compensation is necessary. In part geometry each element is analysed along its tool drive path for previous element and next element. If the tool path starts from that element then drive path is start point or end point of the element. If the drive path does not have any taper element or circular element then tool path follows the same contour. If the drive path has tapered element or circular arc element then tool path offset is given as discussed in 2.1.7. The cutter path varies for each drive path if the contour has taper element or circular element.

CHAPTER IV

TEST EXAMPLES

To test the developed process planning system, three rotational parts comprising different combinations of operations and features are tested. Given the details of part geometry, raw stock geometry and other input data the results are obtained i.e. the operation sequence, cutter path generation and animation for simulation of the tool. The necessary graphical inputs for generating the above information are also discussed.

4.1 EXAMPLE 1:

The part under consideration is as shown in Fig. 4.1. The part has special features such as grooving, threading and blind holle, of this secondary elements are grooving and threading. The part geometry input is given with primitives of point and line which are available in the drawmenu option. Fig. 4.2 shows the main elements (line) below the central line of the path. The number of elements is 10 (line). After the part geometry main elements inputs are over, the inputs for secondary elements (threading, grooving) are given by invoking element in the Draw menu. Once this option is invoked the main elements numbers are written in the middle of the each element as appearing in the screen are shown in Fig. 4.2. The necessary inputs for grooving

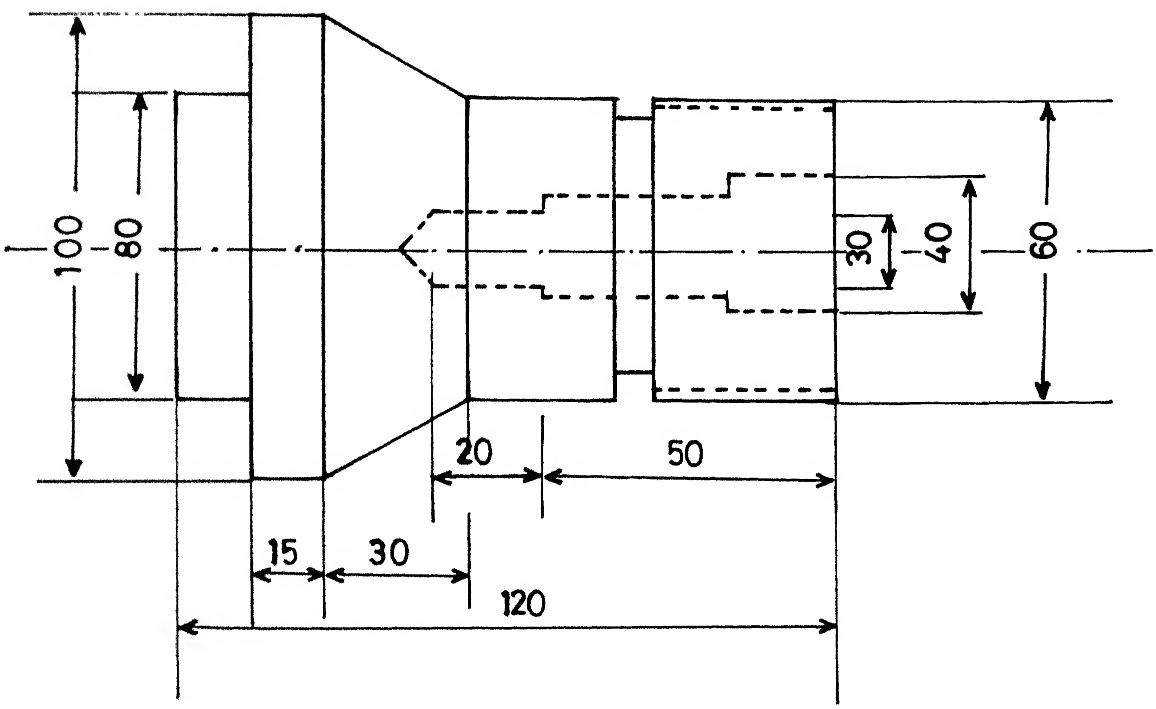


Figure 4.1

Figure - 4.2

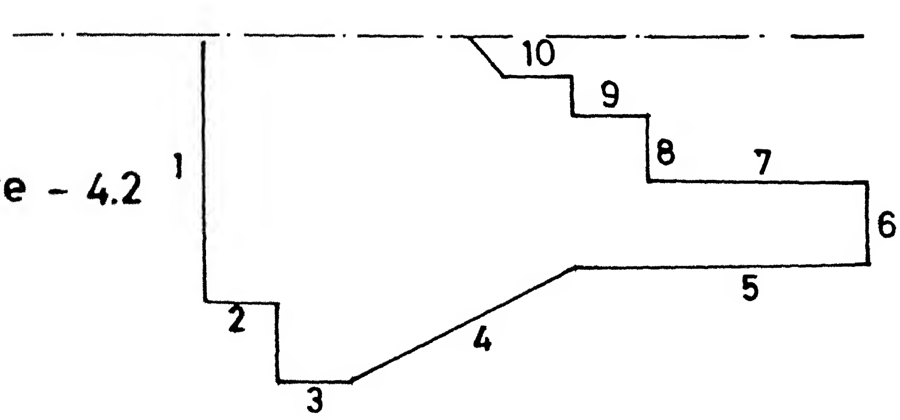
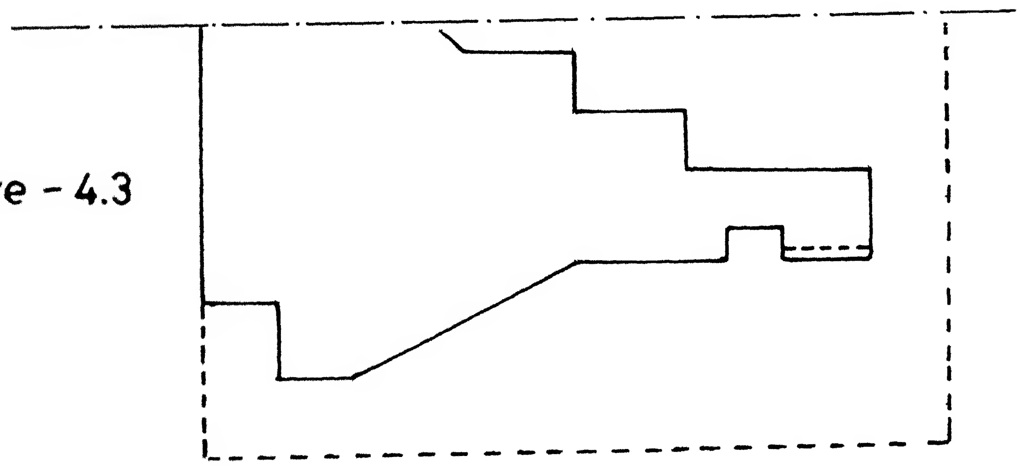


Figure - 4.3



namely grooving width, depth, element number, starting point and for threading pitch, length of the thread, element number are given. After these inputs, the secondary elements are associated to primary elements and displayed in the screen as shown in Fig. 4.3. After this, raw stock geometry input is given with three line elements represented in dotted line in Fig. 4.3. The work material input is given as plain carbon steel. After work material selection the cutting parameters for that material is retrieved and displayed as shown in Table 4.3. The sequencing of operation generated as follows.

The operation number one is facing generates the face including element number 6 and reduces the length to 120 mm. The operation number two is for turning the entire length to reduce the raw stock diameter to 100 mm. The same tool is further extended to perform taper turning of 4th element and turning of 5th element simultaneously. This is accomplished by the following set of tool movements. After completing operation number two, the tool goes on to taper turn and turn both elements 4 and 5 respectively, at the same time. The intersection point of the hypothetical element 4 and the line of travel of the tool on element 5 towards element 4 is calculated by the system. So the tool stops turning the raw stock once it reaches the hypothetical inclined element 4. This is possible only with numerical control machine since two motions are controlled simultaneously. This is the operation number 3. Then drilling to diameter 30 mm length of 70 mm with respect to element number 6. This is followed by

Table 4.3:

Selected Material Plain Carbon Steel

Cutting Speed (Rough Turning)	:	127 m/min.
Cutting Speed (Finish Turning)	:	182.7 m/min.
Cutting Speed (Grooving)	:	93 m/min.
Cutting Speed (Threading)	:	102.3 m/min.
Cutting Speed (Drilling)	:	30.50 m/min
Depth of Cut (Turning)	:	2.54 mm
Depth of Cut (Thread Cutting)	:	0.254 mm

step boring through 9th element till 10th element (5th operation) and step boring through 7th element and till 8th element (6th operation. The finish cutting (external) forms the 7th operation and internal finish cutting forms 8th operation. The 9th and 10th operations grooving and threading respectively. The cutter path with necessary off set which depends on the drive path is displayed. The necessary output tables for operation sequencing along with cutting parametrs cutting time are displayed.

4.2 EXAMPLE 2:

The part geometry is as shown in Fig. 4.4. This parts has the feature of a circular arc and grooving on a tapered element is as shown in Fig. 4.5 of which grooving is the secondary element. Fig. 4.5 shows the main elements (line and arc) below the centre line. The desired secondary element and raw stock geometry is given in Fig. 4.6. Here the selected work material is aluminium. The cutting parameters are displayed as per Table 4.4 Since the part geometry has a through hole part geometry description from point 1. Here the total number of elements are 8 elements of which 7 are line elements and 1 is an arc element. The operation sequence is as follows.

The operation number one is facing generates the face including element number 7. The turning to the largest diameter of the part geometry for the entire length of raw stock forms the operation number 2. This operation generates element number 2. The operation number three is circular contour cutting with turning of element 3 and 4 respectively. This is achieved by the

Table 4.4:

Selected Material Aluminium

Cutting Speed (Rough Turning)	:	248 m/min.
Cutting Speed (Finish Turning)	:	381 m/min.
Cutting Speed (Grooving)	:	310 m/min.
Cutting Speed (Threading)	:	310 m/min.
Cutting Speed (Drilling)	:	79.3 m/min
Depth of Cut (Turning)	:	3.81 mm
Depth of Cut (Thread Cutting)	:	0.381 mm

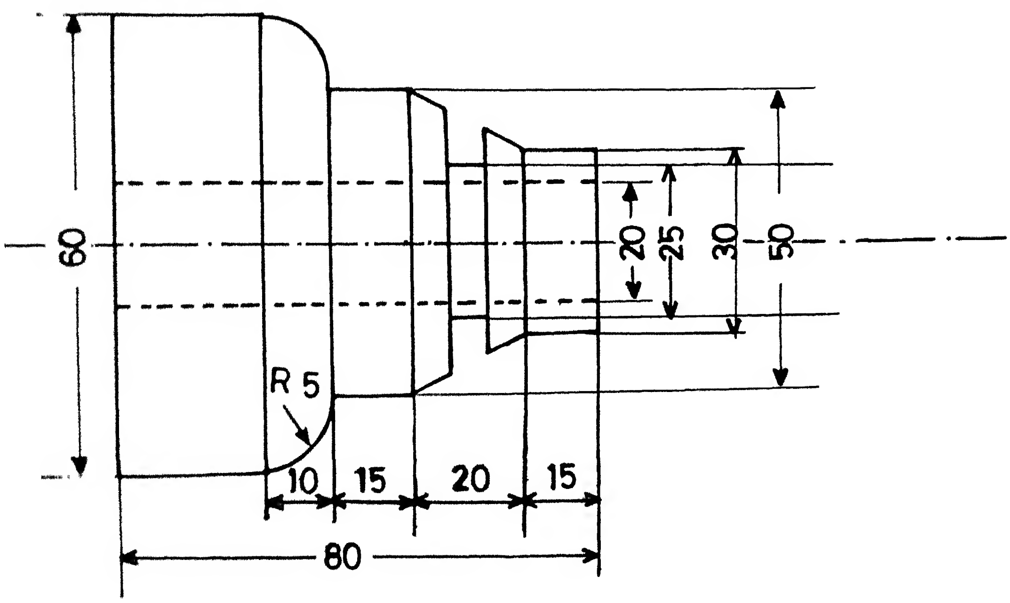


Figure - 4.4

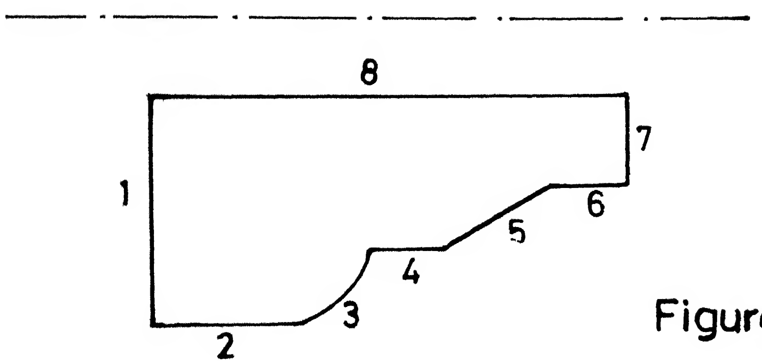


Figure-4.5

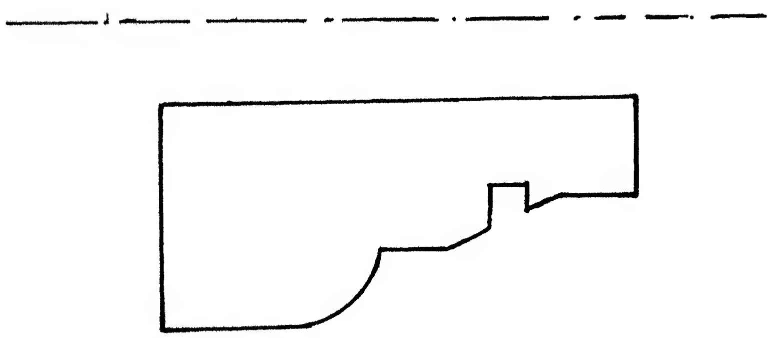


Figure-4.6

following set of tool motions. After completing operation two the tool goes on to contour cutting and turning elements 3 and 4 respectively at the same time. The intersection point of hypothetical element 3 and the line of travel of the tool on element 4 towards element 3 is calculated by the system. So the tool stops turning the raw stock once it reaches hypothetical circular element. Taper turning and turning of element numbers 5 and 6 forms the 4th operation. The fifth operation is through hole drilling of diameter 20 mm. Then finishing of the external operation forms 6th operation. The 7th operation is the grooving in the taper turning element. Based on this the cutter paths is animated on the screen each operation sequence and their cutter path are displayed on the screen.

4.3 EXAMPLE 3:

This part geometry is as shown in Fig. 4.7. This part has the feature of arc (CCLW) and threading. The part geometry has 7 line elements and 1 arc element. The part geometry with main and secondary elements are as shown in Fig. 4.8. Here the selected work material is cast iron. The cutting parameters are displayed in Table 4.5. The operation sequence is as follows.

Facing is carried out to generate the face including element forms the first operation. Then turning continues till largest diameter of the part geometry of 60 mm including diameteral element 2 forms 2nd operation. The 3rd operation is circular contour cutting with turning of element 3 and 4 respectively.

Table 4.5:

Selected Material Cast Iron

Cutting Speed (Rough Turning)	:	108.5 m/min.
Cutting Speed (Finish Turning)	:	201.5 m/min.
Cutting Speed (Grooving)	:	155 m/min.
Cutting Speed (Threading)	:	155 m/min.
Cutting Speed (Drilling)	:	33.50 m/min
Depth of Cut (Turning)	:	3.05 mm
Depth of Cut (Thread Cutting)	:	0.406 mm

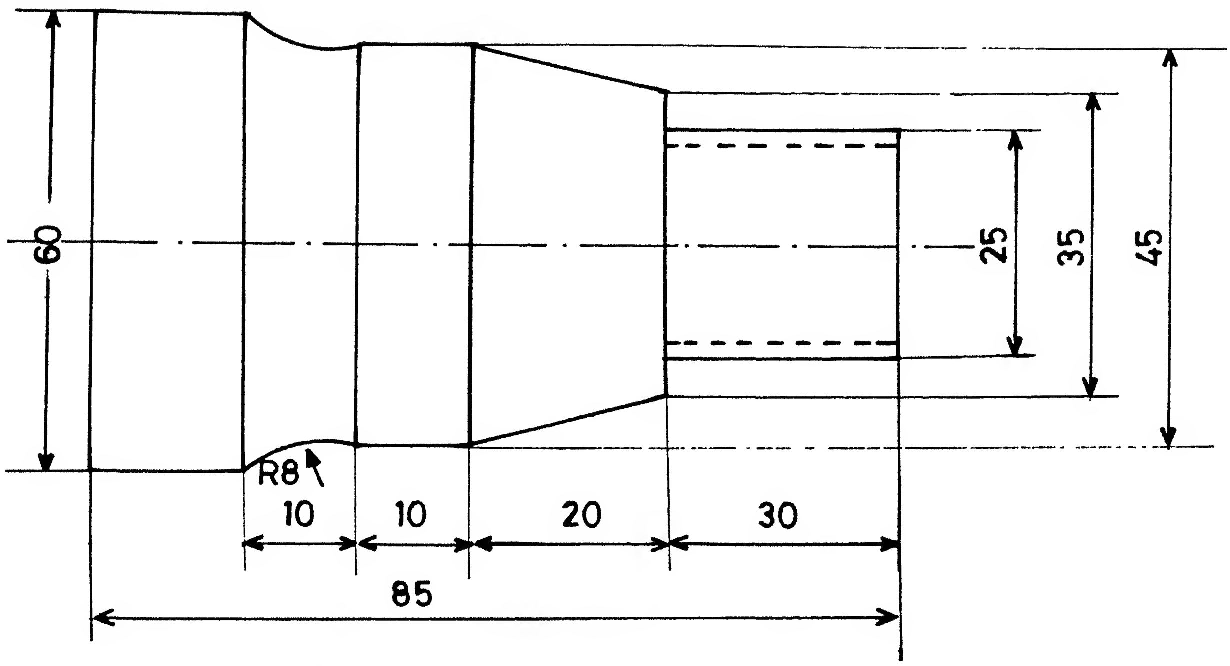


Figure 4.7

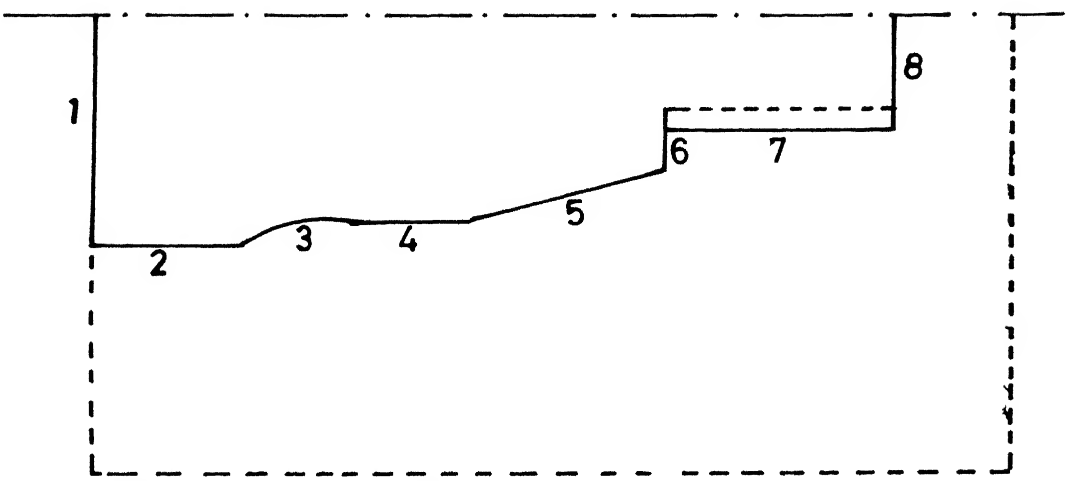


Figure 4.8

Then taper turning is carried out as described earlier in example 1 for generation of element 5 and it is operation number 4. Turning through 7th element till 6th element forms the 5th operation. Finishing along the contour and threading forms 6th and seventh operation respectively.

CHAPTER V

USER'S MANUAL

This user manual gives the user a guide to the process planning system. The system is completely menu driven and utilisation of the system is stated here in terms of individual menu options. The first subsection gives the terminology used in the subsections and preliminary information about operating the menu options. The second subsection describes details of each menu.

The process planning system consists of Dran.pas alongwith typedef.sys, Kernal.sys, Graphix.sys, Window.sys, Strin.pas, Cur.pas, Drt4.pas, Sec.pas, Drg.pas, Arfile.pas, Incom.pas files. The system runs in MS-DOS environment 3.0 version in turbopascal. It occupies 64 KB Ram memory. In order to over come the memory constraints overlay files are created in disk memory and necessary procedure gets loaded into the Ram memory when particular procedure is called.

The cursor movement is done using Up(↑) key and Down (↓) key. The invoking of the cursor is done by pressing 'PgDn' key. The cursor moves in the menu from top to bottom. Keeping the cursor in the required option and by entering 'Return', the option command will be executed. the menus and menu options are described in the next section.

General Screen Scale:

Generally the monitor screen is divided into small pixels to increase resolution. While using a PC with a EGA card the screen dimension would be 640 x 350 pixels and a machine with a HGC card the screen dimensions are given as 720 x 350 pixels. A CGA card offers screen dimension of 600 x 200 pixels. The developed system is adaptable to any of the above cards and the manu window visual screen and input message window maintain a proportion of the occupation of the screen.

Menu Screen:

One fifth of the horizontal and 7/8th of vertical size of the screen is occupied by this screen. This appears at the extreme right of the monitor screen. The menu options are written on a font scale of 1 (9 x 14 pixel size), in EGA, CGA card and a font scale of 2 (6 x 9 pixel size), in HGA card.

Input Message Screen:

This is the bottom portion of the screen where numerical inputs are given by the user. During part geometry descrption and raw stock description on the visual screen the previous point of input entry's coordinates are displayed for reference purpose.

Visual Screen:

The rest of the portion of the screen is termed as the visual screen. This area serves as the drawing board for the part geometry and raw stock. It also displays the list of work material for the user to select the work material. The output displays

concerning cutting parameters, operations sequencing, cutter path simulation and cutter path animation also takes place in this screen.

The following section traverses through the various menus and menu options available in the system and tells what their purposes and functions are for a detailed menu structure see Fig. 2.1.

Mainmenu:

The mainmenu has the following options: settings, drawmenu, operations, cutter path, raw stock, and quit. The drawmenu option will load the submenu draw. These submenu options are used to describe raw stock and part-geometry input. The setting option in the main menu will ask the user input for height or width of the screen. The user has to specify these screen parameters depending on the size of the raw stock and part geometry. The operations menu option will display the outputs of operation sequencing on the screen and rough cutter path. The raw geometry menu option has to be invoked for giving the inputs for the raw stock geometry. The cutter path option is used to generate finish cutter path with necessary offset on the visual screen area. Quit option is for coming out from the system.

Drawmenu:

This menu option is used for geometrical input. Point, line, arc, sec.ele (secondary elements) mainmenu are options available. The point option is used to give input for starting point of the part geometry and raw stock geometry. The line option will load

the submenu line and similarly arc option loads the arc submenu Sec.ele option invokes submenu Sec.ele. Mainmenu option will take back to the main menu.

Linemenu:

This menu has the following options. "EP" (Ending Point) "EP(X)/Angle" (End point (X) angle). "EP(Y)/Angle" (End Poijnt (Y coord)/angle) and Angle/l (Angle/absolute length). For each option the necessary inputs from the user in the input message display zone. After the input the last end point is written at the right bottom of the screen.

Arc Menu:

This menu has the following options CP/EP (Centre point/End point), CP/Angle, (Centre point, angle), CP/Ending angle (Centre point/End point angle) EP/r/CLW (End point/radius/CLW), EP/r/CCLW (End point/radius/CCLW). For each option the user is asked to provide the necessary inputs.

Sec. Ele. Menu:

This menu has threading, and grooving as the secondary element options. For grooving options grooving width, depth, element number are the inputs the user has to provide in input message screen. for threading option, length of the thread, pitch of the thread, length) are the inputs.

CHAPTER VI

SUMMARY

In this chapter the conclusions for the present design and implementation and suggestions for future developments are presented.

6.1 CONCLUSIONS:

The designed process planning system is interactive in nature. In this system the descriptions of the main elements and secondary elements of part geometry, raw stock input and retrieval of cutting parameters are carried out interactively. The process plan output comprises of the operation sequence, generation of cutter path, simulation of cutter path by animation, and total processing time and other necessary process informations are generated with adequate details.

The part geometry, raw stock inputs are specified by the primitives line and arc and they in turn can elaborate possibilities of specifications. The cutting parameters are retrieved based on the material selection. The cutting boundary is extracted from raw stock and part geometry inputs. Offset for finish depth of cut is given in the cutting boundary for finish cutting. Based on the form feature it sequences the operation and generates the cutter location file. It can analyse following the

form features such as facing, turning, taper turning, drilling boring, step boring, external grooving and external threading.

Based on the cutter location file the cutter path is simulated by animation on the screen. Every tool starts from the datum point specified by the user. As the output, the system generates tabulated parameters for process planning and cutter location (CL) files.

6.2 SUGGESTIONS FOR DEVELOPMENT:

The following system can be made more comprehensive by incorporating the following informations.

i) With the addition of group of elements the system can be made to generate complicate profiles and hence the range of components that can be analysed by the system gets increased. For rotational components, the non-rotational features like keyways, splines, cubical surface) etc. can also be incorporated.

ii) A comprehensive Database System can be designed for work material, bar stock standard sizes, cutting parameters, tool geometries etc. These can be stored for easy retrieval and further manipulations.

iii) The more technological parameters analysis such as the effect of slenderness during machining on geometric tolerancing, surface finish, spindle bore constraint, etc. can be analysed.iv) The generation of APT part program or g-code from the cutter path file can also be done. By doing

so the part program can be fed into NC. machine for actual production.

v) The cutting parameters can be optimized based on maximum production or minimum cost keeping the values retrieved from standard tables as initial values.

vi) The same part geometry description can be used for 2D milling but the contour will be a closed one. Process plan and part program for 2D milling can be generated using this.

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